Laboratory
3

Dutch Roll Dynamics

The dSpace Flight Simulator Is Used to Asses the Dutch Roll Mode

Introduction

The purpose of this experiment is to assess the Dutch roll dynamics of an aircraft. Flight test techniques are employed to excite, measure, and analyze the Dutch roll mode. Lateral stability derivatives of an aircraft are modified to achieve Level I flying qualities.

A. Quick Start Procedures for the dSpace Simulator. The student will execute the proper procedures for turning on the equipment and loading the aircraft simulation required of this lab.

B. Visualizing Dutch Roll Dynamics, 2 & 3 Degrees of Freedom. The Dutch roll motion of the Navion aircraft will be examined. Control Desk will be used to limit aircraft dynamics to 2 and 3 lateral-directional degrees of freedom. The response resulting from a rudder pulse will be captured and graphically analyzed. Measured Dutch roll frequency and damping will be used to classify the flying qualities of the Navion.

C. Major Stability Derivatives in Dutch Roll Dynamics. The student will use Control Desk to modify the dihedral effect, directional stability, and yaw damping of the Navion aircraft. The resulting influence on the Dutch roll motion will be observed, quantified, and correlated with changes in flying qualities.

D. Flight Test: Dutch Roll Dynamics. The student will load an unknown aircraft and test its lateral-directional flying qualities with respect to its Dutch roll mode. Target values for lateral-directional stability derivatives will be suggested to achieve Level I flying qualities.

Part A. Quick Start Procedures for the dSpace Simulator

A detailed description of the dSpace flight simulator can be found in Laboratory 1, parts A through E. This lab assumes a basic knowledge of the simulator and its operating procedures. The major steps in booting the dSpace simulator are listed below.

- ❑ Turn the Dome and Dukane projectors on.
- ❑ Boot the four simulator PCs. Note: Sim PC password is “netman”.
- ❑ Establish the serial connections (Serial Link), and start AVDS on the Dome and OVHD PCs. Select "File | Simulation Init | Matlab_AC.ini" .
- ❑ Start Control Desk on Sim PC; resize window.
- ❑ Open the BasicAircraft.cdx experiment in the C:\Experiments\BasicAircraft directory.

- Double click on the “aircraft_d.mdl” file in the Experiment file browser.
- Move to the Models directory in Matlab.
- Type "MasterPanel" at the command prompt. Choose "Select Aircraft" from the figure, and load the Navion aircraft data.

Part B. Visualizing Dutch Roll Dynamics, 2 & 3 Degrees of Freedom

The Dutch roll motion of an aircraft is perhaps the most complicated of the dynamic modes. While it is typically characterized as a pair of complex roots, those roots are not separated in frequency from the other lateral-directional dynamics as well as were the long and short period modes along the longitudinal axes. As a result, it is more difficult to separate, so called, pure Dutch roll motion from other lateral-directional motions, principally the spiral mode. We will use the simulator's ability to restrict motion along user-defined directions to isolate and analyze the Dutch roll characteristics.

- Bring up the Simulink model, "aircraft_D.mdl". Select "Simulation **|** Simulation Parameters **|** Real-time Workshop **|** Build".

2 Degree of Freedom Motion

Ensure that the simulation is running. Select "Start" in AVDS if you have not already done so in order to see the aircraft motion. Because we are interested only in lateral dynamics, we restrict the longitudinal dynamics.

- In Control Desk, Select Animation Mode for the layout pages, and bring forward the layout page labeled "Integrators."
- Disable the pitch angle, velocity, and angle of attack integrators. Be sure that the aircraft is at the trimmed flight condition when the integrators are disabled.

This restricts the aircraft motion to level flight at 105 kts, although the aircraft is free to bank, slip, and turn. If we consider Dutch roll motion to be analogous to a second order, spring-mass-damper, system, then the motion would consist primarily of sideslipping and yawing motions. To simulate this we should restrict the bank angle to wings level.

- With the wings level, disable the bank angle integrator.

A rudder pulse is used to excite the lateral-directional dynamics. A rudder pulse is a fairly large and somewhat rapid cycling of the rudder. The control is released after the pulse to allow the airplane to oscillate freely without pilot inputs. In order to excite the dynamics, you should attempt to apply the pulse at about the same frequency as the dynamic mode being tested. To excite the Dutch roll, cycle the rudder left-to-right, and back to center in about 2 seconds. Practice until you are satisfied with your experimental technique.

- Capture 15 seconds of response to a rudder pulse. Remember, you are interested in the transient response with the rudder neutral after the rudder pulse has been applied.
- View the time history of sideslip and yaw rate from captured data.

- ❑ Using the Addendum, graphically estimate the Dutch roll natural frequency and damping.
- ❑ Damping: __________ Natural Frequency: ___________ (radians/second)

3 Degree of Freedom Motion

The 2-degree of freedom Dutch roll approximation results in motion about the directional axis that is analogous to short period mode motion about the pitch axis. The directional stability derivative, N_β, plays the same role as M_α, namely the spring force in the second order system. The yaw rate damper, N_r, is analogous to $M_{q,\dot{\alpha}}$. The 2-degree of freedom approximation, however, is only a rough estimate because the Dutch roll is really a three-degree of freedom motion. The sideslip during the Dutch roll causes a rolling moment. The rolling moment results in banking action, which in turn influences the yawing motion. To see this, we will need to add a degree of freedom of motion to the simulation.

- ❑ Enable the Bank angle integrator in Control Desk.
- ❑ Apply a rudder pulse and observe the lateral dynamics.
- ❑ Capture fifteen seconds of response to a properly applied rudder pulse.
- ❑ View the time history of sideslip and yaw rate from captured data.
- ❑ Using the Addendum, graphically estimate the Dutch roll natural frequency and damping.
- ❑ Damping: __________ Natural Frequency: ___________ (radians/second)

Your test results should have been in close agreement with the two degree of freedom test. The feel of the motion, however, is quite different. The added dynamics are termed the roll-to-yaw ratio of the aircraft. The roll-to-yaw ratio is graphically presented by plotting sideslip angle along the x-axis and bank angle along the y-axis. The feature to view this relationship is included in the View Data figure.

- ❑ Select Dutch roll from the pull-down menu in the View Data figure, and press Display
- ❑ Graphically estimate the Roll-to-Yaw Ratio: __________

The roll-to-yaw motion in the aircraft is most easily seen by observing the path of the wingtip on the horizon. Low roll-to-yaw ratios are typical of tactical jet aircraft. Lateral gusts or excursions result in pure heading changes. The Dutch roll influence on the roll performance is small. Moderate roll-to-yaw ratios are typical of general aviation aircraft. Enough rolling motion is generated by sideslip that the pilot can use the rudder to bank the aircraft if required. The coupling between lateral and directional motions necessitate that aileron and rudder inputs be coordinated in a turn. High roll-to-yaw ratios are typical of aircraft like sailplanes. Large rolling moments are generated by sideslip excursions. Roll performance is severely degraded without effective rudder coordination.

C. Major Stability Derivatives in Dutch Roll Dynamics

The directional stability and dihedral effect of an aircraft often play competing roles in the Dutch roll motion. The aircraft designer desires to make the aircraft stable in both direction and roll. However, too much of either requirement adversely affects the Dutch roll motion. The aircraft designer must compromise with an adequate, although perhaps not ideal, amount of each. Increasing the yaw damping of the lateral dynamics results in improved damping of the Dutch roll. However, physically increasing the yaw damping is difficult as it normally entails increasing the tail area or wing geometry. Sometimes, simply adding a ventral fin will work. At other times, the aircraft requires stability augmentation of the lateral dynamics via a yaw rate damper. The proper design of a yaw rate damper is an appropriate topic for a course in control theory.

Dihedral Effect

Roll stability is achieved by incorporating sufficient dihedral effect in the aircraft design. Many design parameters, such as geometric dihedral of the wing, wing sweep, wing aspect ratio, and fuselage location, contribute to the dihedral effect of the aircraft. We will leave the difficult task of obtaining the proper balance of these items to the aircraft designer for now, and look at the stability derivative most closely associated with dihedral effect, C_{l_β}.

- ❑ With the simulation running in Animation Mode, and three lateral-directional degrees of freedom enabled, bring up the lateral stability derivative layout.
- ❑ Approximately double the dihedral effect by changing C_{l_β} from -0.074 to -0.15.
- ❑ Excite the Dutch roll dynamics using a rudder pulse, and examine the response.
- ❑ Return C_{l_β} to its nominal value.
- ❑ Damping: __________ Natural Frequency: ____________ (radians/second)
- ❑ Roll-to-Yaw Ratio: __________

You should have noticed a marked decrease in the Dutch roll damping, and increase in the roll-to-yaw ratio. Too much dihedral effect, however, can create an unstable Dutch roll mode.

Directional Stability

Directional stability is generally achieved through the proper design of the vertical tail. Sufficient yaw stiffness is required to keep the aircraft pointed into the relative wind. The weathercock stability derivative, C_{N_β}, is influenced by the tail volume. Other design considerations, such as the ability to counter asymmetric thrust, hold ground track in a crosswind, or recover from a spin, often force this derivative to be larger than is required for simple stability. Increased static stability is not necessarily associated with improved flying qualities.

- With the simulation running in Animation Mode, and three degrees of lateral-directional freedom enabled, bring up the lateral stability derivative layout.
- Approximately double the directional stability by changing C_{N_β} from 0.071 to 0.15.
- Excite the Dutch roll dynamics using a rudder pulse, and examine the response.
- Return C_{N_β} to its nominal value.
- Damping: __________ Natural Frequency: ___________ (radians/second)
- Roll-to-Yaw Ratio: __________

You should have noticed a marked decrease in the Dutch roll damping and increase in the natural frequency. The roll-to-yaw ratio is approximately the same. Excessive weathercock stability can also destabilize the spiral mode. Did doubling the weathercock stability, C_{N_β}, of the Navion aircraft improve the overall stability of the later-directional dynamics?

Yaw Rate Damping

Yaw rate damping, C_{N_r}, directly affects the damping of the Dutch roll dynamics. The magnitude of C_{N_r} depends largely on the size of the vertical tail, and the geometry of the wing, neither of which can be easily changed without large ramifications for the rest of the design. While the physical geometry of the plane is difficult to change to affect C_{N_r}, it is possible to add a stability augmentation system that artificially increases the yaw damping.

- With the simulation running in Animation Mode, and three lateral-directional degrees of freedom enabled, bring up the lateral stability derivative layout.
- Approximately double the yaw rate damping by changing C_{N_r} from -0.125 to -0.25.
- Excite the Dutch roll dynamics using a rudder pulse, and examine the response.
- Return C_{N_r} to its nominal value.
- Damping: __________ Natural Frequency: ___________ (radians/second)
- Roll-to-Yaw Ratio: __________

D. Flight Test: Dutch Roll Dynamics

Empirical evidence suggests that there are combinations of Dutch roll damping, frequency, and roll-to-yaw ratios that provide satisfactory lateral-directional flying qualities. Aircraft are grouped by class. Class I aircraft include light airplanes like the Navion. Class II and III are aircraft of increasing weight and size. Class IV airplanes are fighters/attack. Flight phase categories are grouped by letter. Category A is rapid maneuvering; Category B is cruise; and Category C is take-off and landing. For a more complete description see MIL-F-8785C.

Therefore, the Navion example would be termed Class I, Category B. Minimum Dutch roll frequency and damping requirements from MIL-F-8785C for all Class and Category are shown in the table below.

TABLE VI. Minimum Dutch roll frequency and damping.

Flight Phase Level	Flight Phase Category	Class	Min ζ_d*	Min $\zeta_d\omega_{n_d}$* rad/sec.	Min ω_{n_d} rad/sec.
1	A (CO and GA)	IV	0.4	-	1.0
	A	I, IV	0.19	0.35	1.0
		II, III	0.19	0.35	0.4**
	B	All	0.08	0.15	0.4**
	C	I, II-C, IV	0.08	0.15	1.0
		II-L, III	0.08	0.10	0.4**
2	All	All	0.02	0.05	0.4**
3	All	All	0	-	0.4**

In general, an aircraft must meet Level 1 flying quality standards. Based on your tests of the Dutch roll mode of the Navion aircraft, does the Navion meet Level 1 requirements for Dutch roll?

Experimental Aircraft Dutch Roll Measurement

- ❑ Load the aircraft file, “Experimental A” using the Select Aircraft figure.
- ❑ Build the simulation, and run it in Control Desk.
- ❑ Excite the Dutch roll dynamics using a rudder pulse, and record the dynamic response.
- ❑ Use the View Data figure to ensure that your data is adequate for post-processing.
- ❑ Damping: __________ Natural Frequency: ___________ (radians/second)
- ❑ Roll-to-Yaw Ratio: __________
- ❑ Save the data to floppy.

Recall that the data is saved in a matrix whose rows and columns are given below.

Variable Name: 'data' (17 rows by n columns, where n = capture time/0.03)

Rows: 1: Time (seconds)

2: Velocity (ft/sec)	3: AOA (radians)	4: Sideslip (radians)
5: Roll rate (rad/s)	6: Pitch rate (rad/s)	7: Yaw rate (rad/s)
8: Heading (radian)	9: Pitch (radian)	10: Bank Angle (radian)

11: X position (ft)	12: Y position (ft)	13: Z position (ft)
14: Aileron deflect (rad)	15: Elevator deflect (rad)	16: Throttle (percent)
17: Rudder deflect (rad)		

Column: One column for each data point every 0.03 seconds.

Experimental Aircraft Dutch Roll Design

Return to the Experimental A aircraft running on the simulator. Design requirements call for a roll-to-yaw ratio of 0.8:1 to 1.2:1 . Furthermore, the aircraft must meet Level I Dutch roll flying qualities.

- ❑ Excite the Dutch roll dynamics, and record the response.
- ❑ Change #1: Does the Experimental A aircraft meet roll-to-yaw ratio specifications? If not, what derivative would you suggest the aircraft designer attempt to influence with design changes, and to what extent (give a numerical target value for this derivative)?
- ❑ Change #2: Does the Experimental aircraft posses Level I flying qualities? If the designer desires to correct any deficiencies with the inclusion of a yaw rate damper, what should the effective value of the yaw rate damping derivative, C_{N_r} , be with the yaw rate damper on?
- ❑ Test your aircraft with these changes made, and save the captured data.

Shutdown

You can shutdown each software application. When prompted by Control Desk or MATLAB, DO NOT SAVE ANY CHANGES. Use a file manager to move your flight test data files to a floppy. The files are in the Experiment/BasicAircraft/CapturedData directory.

- ❑ Shutdown the computers, and turn off the Dome and Dukane projectors.

Deliverables

Prepare a “Results and Analysis” section of a report that demonstrates your understanding of the Dutch roll dynamics of an aircraft.

- ❑ Present your results for the Dutch roll flying qualities of the original Experimental A aircraft.
- ❑ Present your results for the Dutch roll flying qualities of the modified Experimental A aircraft should the designer implement the changes you suggest.

Addendum

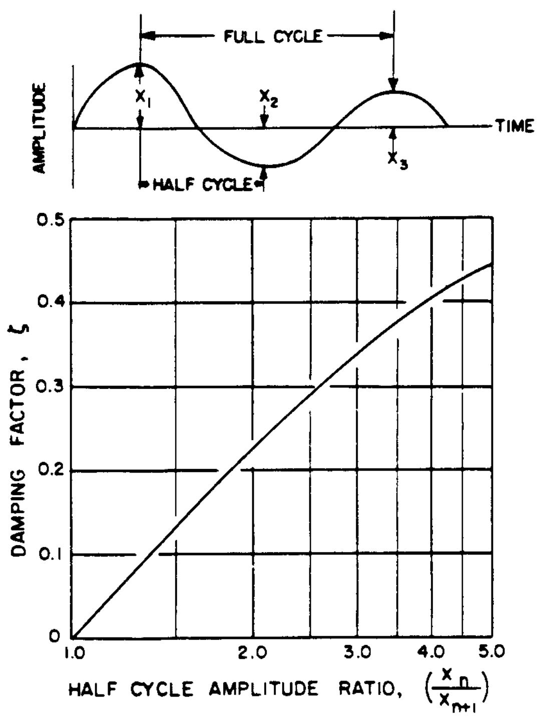
You may find the following information from the Navy Test Pilot Manual useful.

$$\tau = Full\,Cycle \quad (period)$$

$$\zeta = Damping$$

$$\omega_d = \frac{2\pi}{\tau} \quad (damped\ natural\ frequency)$$

$$\omega_n = \frac{\omega_d}{\sqrt{1-\zeta^2}} \quad (undamped\ natural\ frequency)$$



FOR OSCILLATORY DIVERGENCE ($\zeta < 0$), MERELY CHANGE HORIZONTAL SCALE TO $\left(\frac{X_{n+1}}{X_n}\right)$ AND CHANGE VERTICAL SCALE TO NEGATIVE SIGN.